

# Math 121 Class notes

## Fall 2024

Peter Westerbaan

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## 1.1: Solutions of Linear Equations and Inequalities in One Variable

### Definition.

A **function**  $f$  is a special relation between  $x$  and  $y$  such that each input  $x$  results in *at most* one  $y$ . The symbol  $f(x)$  is read “ $f$  of  $x$ ” and is called the **value of  $f$  at  $x$**

**Example.** Let  $f(x) = \frac{x^2}{2} + x$ . Evaluate the following:

$$f(1)$$

$$f\left(\frac{1}{2}\right)$$

$$f(-2)$$

$$f(0)$$

$$f(f(x))$$

### Composite Functions:

Let  $f$  and  $g$  be functions of  $x$ . Then, the **composite functions**  $g$  of  $f$  (denoted  $g \circ f$ ) and  $f$  of  $g$  (denoted  $f \circ g$ ) are defined as:

$$(g \circ f)(x) = g(f(x))$$

$$(f \circ g)(x) = f(g(x))$$

**Example.** Let  $g(x) = x - 1$ . Find:

$$(g \circ f)(x)$$

$$(f \circ g)(x)$$

## Operations with Functions:

Let  $f$  and  $g$  be functions of  $x$  and define the following:

Sum	$(f + g)(x) = f(x) + g(x)$
Difference	$(f - g)(x) = f(x) - g(x)$
Product	$(f \cdot g)(x) = f(x) \cdot g(x)$
Quotient	$\left(\frac{f}{g}\right)(x) = \frac{f(x)}{g(x)}$ if $g(x) \neq 0$

### Definition.

An **expression** is a meaningful string of numbers, variables and operations:

$$3x - 2$$

An **equation** is a statement that two quantities or algebraic expressions are equal:

$$3x - 2 = 7$$

A **solution** is a value of the variable that makes the equation true:

$$3(3) - 2 = 7$$

$$9 - 2 = 7$$

$$7 = 7$$

A **solution set** is the set of ALL possible solutions of an equation:

$3x - 2 = 7$  only has the solution  $x = 3$ ,

$2(x - 1) = 2x - 2$  is true for all possible values of  $x$ .

## Properties of Equality:

**Substitution Property:** The equation formed by substituting one expression for an equal expression is equivalent to the original equation:

$$\begin{aligned}3(x - 3) - \frac{1}{2}(4x - 18) &= 4 \\3x - 9 - 2x + 9 &= 4 \\x &= 4\end{aligned}$$

**Addition Property:** The equation formed by adding the same quantity to both sides of an equation is equivalent to the original equation:

$$\begin{array}{ll}x - 4 = 6 & x + 5 = 12 \\x - 4 + 4 = 6 + 4 & x + 5 + (-5) = 12 + (-5) \\x = 10 & x = 7\end{array}$$

**Multiplication Property:** The equation formed by multiplying both sides of an equation by the same *nonzero* quantity is equivalent to the original equation:

$$\begin{array}{ll}\frac{1}{3}x = 6 & 5x = 20 \\3\left(\frac{1}{3}x\right) = 3(6) & \frac{5x}{5} = \frac{20}{5} \\x = 18 & x = 4\end{array}$$

## Solving a linear equation:

Using the properties of equality above, we can solve any linear equation in 1 variable:

**Example.** Solve  $\frac{3x}{4} + 3 = \frac{x-1}{3}$

1. Eliminate fractions:

$$12\left(\frac{3x}{4} + 3\right) = 12\left(\frac{x-1}{3}\right)$$

2. Remove/evaluate parenthesis:

$$9x + 36 = 4x - 4$$

3. Use addition property to isolate the variable to one side:

$$9x + 36 \text{--}36 \text{--}4x = 4x - 4 \text{--}36 \text{--}4x$$

4. Use multiplication property to isolate variable:

$$\frac{5x}{5} = \frac{-40}{5}$$

5. Verify solution via substitution:

$$\underbrace{\frac{3(-8)}{4} + 3}_{-6 + 3 = -3} \stackrel{?}{=} \underbrace{\frac{(-8) - 1}{3}}_{\frac{-9}{3} = -3}$$

**Example.** Solve the following:

$$\frac{3x+1}{2} = \frac{x}{3} - 3$$

$$\frac{2x-1}{x-3} = 4 + \frac{5}{x-3}$$

**Example.** Solve  $-2x + 6y = 4$  for  $y$



**Example.** Suppose that the relationship between a firm's profit,  $P$ , and the number of items sold,  $x$ , can be described by the equation

$$5x - 4P = 1200$$

a) How many units must be produced and sold for the firm to make a profit of \$150?

b) Solve this equation for  $P$  in terms of  $x$ . Then, find the profit when 240 units are sold.

**Definition.**

An **inequality** is a statement that one quantity is greater than (or less than) another quantity.

**Properties of Inequalities**

**Substitution Property:** The inequality formed by substituting one expression for an equal expression is equivalent to the original inequality:

$$5x - 4x + 2 < 6$$

$$x < 4 \Rightarrow \text{The solution set is } \{x : x < 6\}$$

**Addition Property:** The inequality formed by adding the same quantity to both sides of an inequality is equivalent to the original inequality:

$$x - 4 < 6$$

$$x - 4 + 4 < 6 + 4$$

$$x < 10$$

$$x + 5 \geq 12$$

$$x + 5 + (-5) \geq 12 + (-5)$$

$$x \geq 7$$

**Multiplication Property** The inequality formed by multiplying both sides of an inequality by the same *positive* quantity is equivalent to the original inequality. The direction of the inequality is flipped when multiplying by a *negative* quantity:

$$\frac{1}{3}x > 6$$

$$3\left(\frac{1}{3}x\right) > 3(6)$$

$$x > 18$$

$$5x - 5 \leq 6x + 20$$

$$-x \leq 25$$

$$x \geq -25$$



**Example.** Solve

$$-x + 8 \leq 2x - 4$$

first by gathering the  $x$  variable on the left, then again on the right. See that the multiplication property holds in both cases. Plot the solution set on a numberline.



**Example.** Plot the following inequalities:

$$x \leq 2$$

$$x > -3$$



### 1.3: Linear Functions

**Definition.**

A **linear function** is a function of the form

$$y = f(x) = ax + b$$

where  $a$  and  $b$  are constants.

**Example.**  $y = -2x + 8$



A linear function can be uniquely determined using only *two* distinct points.

**Definition.**

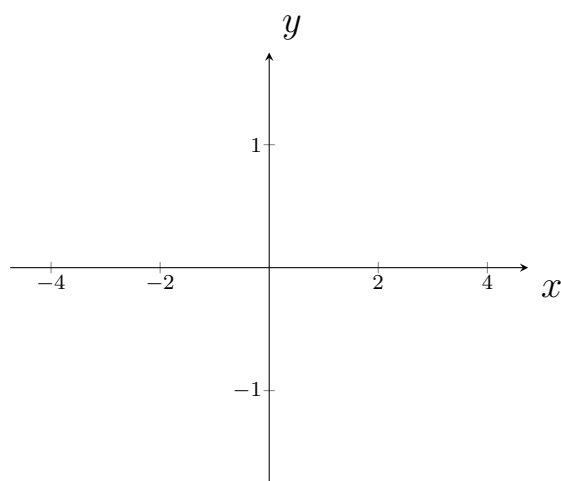
The point(s) where a graph intersects the axes are called intercepts. The  $x$ -coordinate of the point where the function intersects the  $x$ -axis is called the  **$x$ -intercepts**. The  $y$ -coordinate of the point where the function intersects the  $x$ -axis is called the  **$y$ -intercepts**.

- To solve for the  $y$ -intercept:
  - Set  $x = 0$ ,
  - Solve for  $y$ .
- To solve for the  $x$ -intercept:
  - Set  $y = 0$ ,
  - Solve for  $x$ .

**Example.** Find the intercepts and graph the following lines:

$$3x + 2y = 12$$

$$x = 4y$$



**Definition.**

If a nonvertical line passes through the points  $P_1(x_1, y_1)$  and  $P_2(x_2, y_2)$ , its **slope**, denoted by  $m$ , is found using

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x}$$

$\Delta y$  is “delta  $y$ ”, and represents the change in  $y$

$\Delta x$  is “delta  $x$ ”, and represents the change in  $x$

*Note:* The slope of a vertical line is undefined.

**Example.** Find the slope of the line passing through the points  $(-2, 1)$  and  $(5, 3)$ .

*Note:*

- Two distinct nonvertical lines are *parallel* if and only if their slopes are *equal*.
- Two distinct nonvertical lines are *perpendicular* if and only if their slopes are *negative reciprocals*:  
e.g. If  $\ell_1$  has a nonzero slope  $m$ , then  $\ell_2$  is perpendicular if its slope is  $-1/m$ .

## Point-slope form

**Definition.**

The equation of the line passing through the point  $(x_1, y_1)$  with slope  $m$  can be written in the point-slope form:

$$y - y_1 = m(x - x_1)$$

**Example.** Find the equation of each line that passes through the point  $(-3, 4)$  and has

a slope of  $m = \frac{1}{4}$

the point  $(-2, 1)$  on the line

a slope of zero (horizontal)

an undefined slope (vertical)

## Slope-intercept form

**Definition.**

The slope-intercept form of the equation of a line with slope  $m$  and  $y$ -intercept  $b$  is

$$y = mx + b$$

**Example** (Example 7, p.82). The population of U.S. males,  $y$  (in thousands), projected from 2015 to 2060 can be modeled by

$$y = 1125.9x + 142,960$$

where  $x$  is the number of years after 2000.

- Find the slope and  $y$ -intercept of the graph of this function.
- What does the  $y$ -intercept tell us about the population of U.S. males?
- Interpret the slope as a rate of change.

## Forms of Linear Equations

General form:  $Ax + By = C$

Point-slope form:  $y - y_1 = m(x - x_1)$

Slope-intercept form:  $y = mx + b$

Vertical line:  $x = a$

Horizontal line:  $y = b$

## 1.4: Graphs and Graphing Utilities

As graphing calculators are *not* required for this course, we will use Desmos:

[desmos.com/calculator](https://desmos.com/calculator)

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**Example.** For a certain city, the cost  $C$  of obtaining drinking water with  $p$  percent impurities (by volume) is given by

$$C = \frac{120,000}{p} - 1200$$

The equation for  $C$  requires that  $p \neq 0$ , and because  $p$  is the percent impurities, we know  $0 < p \leq 100$ . Use the restriction on  $p$  and a graphing calculator to obtain an accurate graph of the equation.





## 1.5 Solutions of Systems of Linear Equations

$$\text{🍏} + \text{🍏} + \text{🍏} = 18$$

$$\text{🍏} + \text{🍌} + \text{🍌} = 14$$

$$\text{🍌} - \text{🍒} = 2$$

$$\text{🍒} + \text{🍏} + \text{🍌} = ?$$

### Definition.

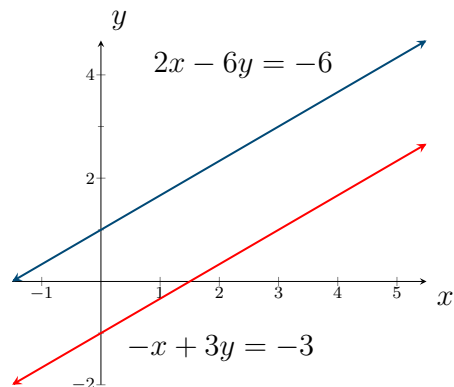
A **system of equations** is 2 (or more) equations. The ordered pairs  $(x, y)$  that satisfies *all* equations in the system are the **solutions** of the system.

When solving a system of linear equations, there are three possible outcomes:

1. No solution (*Inconsistent*),
2. Exactly one solution,
3. Infinitely many solutions (*Dependent*).

**Example.** Use graphing to find the solutions to the following systems

$$\begin{aligned} 2x - 6y &= -6 \\ -x + 3y &= -3 \end{aligned}$$



$$\begin{aligned} 4x + 3y &= 11 \\ 2x - 5y &= -1 \end{aligned}$$



$$\begin{aligned} -4x + 3y &= -2 \\ 8x - 6y &= 4 \end{aligned}$$



**Equivalent systems** result when

1. One expression is replaced by an equivalent expression.
2. Two equations are interchanged.
3. A multiple of one equation is added to another equation.
4. An equation is multiplied by a nonzero constant.

### Substitution Method

**Example.** Solve the system  $\begin{cases} 2x + 3y = 4 \\ x - 2y = 3 \end{cases}$

1. Solve one equation for either one of the variables in terms of the other.

$$x = 2y + 3$$

2. Substitute this expression into the other equation to give the equation in one unknown.

$$2(\textcolor{red}{2}y + \textcolor{red}{3}) + 3y = 4$$

3. Solve this equation for the unknown.

$$4y + 6 + 3y = 4$$

$$7y = -2 \Rightarrow y = -\frac{2}{7}$$

4. Substitute solution into the equation in Step 1.

$$x = 2\left(-\frac{\textcolor{red}{2}}{\textcolor{red}{7}}\right) + 3 \Rightarrow x = \frac{17}{7}$$

5. Check the solution  $(x, y)$ .

$$2\left(\frac{\textcolor{red}{17}}{\textcolor{red}{7}}\right) + 3\left(-\frac{\textcolor{red}{2}}{\textcolor{red}{7}}\right) = 4$$

$$\left(\frac{\textcolor{red}{17}}{\textcolor{red}{7}}\right) - 2\left(-\frac{\textcolor{red}{2}}{\textcolor{red}{7}}\right) = 3$$

**Example.** Use the substitution method to solve the system

$$4x + 5y = 18 \quad (1)$$

$$3x - 9y = -12 \quad (2)$$

## Elimination Method

**Example.** Solve the system  $\begin{cases} 2x - 5y = 4 \\ x + 2y = 3 \end{cases}$

1. Multiply one or both equations by a nonzero number so the coefficients of one of the variables may cancel.

$$\Rightarrow \begin{cases} 2x - 5y = 4 \\ -2x - 4y = -6 \end{cases}$$

2. Add or subtract the equations to eliminate one of the variables.

$$0x - 9y = -2$$

3. Solve for the remaining variable.

$$\Rightarrow y = \frac{2}{9}$$

4. Substitute solution in one of the original equations and solve for the other variable.

$$2x - 5\left(\frac{2}{9}\right) = 4 \Rightarrow x = \frac{23}{9}$$

5. Check the solution  $(x, y)$

$$\begin{aligned} 2\left(\frac{23}{9}\right) - 5\left(\frac{2}{9}\right) &= 4 \\ \left(\frac{23}{9}\right) + 2\left(\frac{2}{9}\right) &= 3 \end{aligned}$$

**Example.** Use the elimination method to solve the following systems:

$$2x - 6y = -6$$

$$-x + 3y = -3$$

$$4x + 3y = 11$$

$$2x - 5y = -1$$

$$-4x + 3y = -2$$

$$8x - 6y = 4$$

**Example.** A nurse has two solutions that contain different concentrations of a certain medication. One is a 12.5% concentration, and the other is a 5% concentration. How many cubic centimeters of each should she mix to obtain 20 cubic centimeters of an 8% concentration?

**Example.** Using U.S. Bureau of Labor Statistics data for selected years from 1950 and projected to 2050, the number of men  $M$  and women  $W$  in the workforce (both in millions) can be modeled by the functions

$$M(t) = 0.591t + 37.3 \quad \text{and} \quad W(t) = 0.786t + 13.1$$

where  $t$  is the number of years after 1940. Find the year these functions predict that there will be equal numbers of men and women in the U.S. workforce.

